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Optimizing Logistics Support for Ballistic Missile Defense Ships in Sixth Fleet

20 November 2013

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Abstract

This research analyzes the optimal and most cost-efficient stationing of critical ship parts that will directly support Ballistic Missile Defense (BMD) ships deployed and stationed in Europe. The goal is to inform and recommend to decision-makers where and how many critical parts should be staged to best support the operational readiness of BMD ships on European Phased Adaptive Approach (EPAA) missions. To effectively accomplish this task, the research analyzes eight high-demand, high-dollar value spares that are forward-staged in Sigonella, Italy. Through modeling and simulation, we determine the most effective method to optimize ship readiness in a cost constrained environment.

Keywords: AEGIS, Ballistic Missile Defense, BMD, Sixth Fleet, Optimization, Modeling

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List of Acronyms and Abbreviations

AAW	Anti-Air Warfare
ACS	AEGIS Combat System
AMC	Air Mobility Command
AOR	Area of Responsibility
AWS	AEGIS Weapon System
BMD	Ballistic Missile Defense
BMDS	Ballistic Missile Defense System
CAT	Category
CASREP	Casualty Report
CENTCOM	Central Command
CG	Guided Missile Cruiser
CLF	Combat Logistics Force
COCOM	Combatant Commander
CONUS	Continental United States
COSAL	Coordinated Shipboard Allowance List
CTF	Combined Task Force
DDG	Guided Missile Destroyer
DDSI	Defense Distribution Depot Sigonella
DLA	Defense Logistics Agency
DoD	Department of Defense
EPAA	European Phased Adaptive Approach
EUCOM	European Command
FDNF	Forward-Deployed Naval Forces
FLC	Fleet Logistics Center
F/AD	Force Activity Designator
FY	Fiscal Year
GAO	Government Accountability Office
GBI	Ground-Based Interceptor

GLS	Global Logistics Support
ICBM	Intercontinental-Range Ballistic Missile
JSDF	Japanese Self-Defense Force
MDA	Missile Defense Agency
MILAIR	Military Aircraft
MSC	Military Sealift Command
MRBM	Medium-Range Ballistic Missile
NAS	Naval Air Station
NAVAIRTERM	Naval Air Terminal
NIIN	National Item Identification Number
NSA	Naval Support Activity
NATO	North Atlantic Treaty Organization
NAVSUP	Naval Supply Systems Command
OPAREA	Operating Area
PACOM	Pacific Command
PUK	Pack-Up Kit
RHIB	Rigid Hull Inflatable Boat
SLBM	Submarine-Launched Ballistic Missile
SSBN	Nuclear-Powered Ballistic-Missile Submarine
SSGN	Nuclear-Powered Cruise-Missile Submarine
WSS	Weapon Systems Support

I. PURPOSE

A. PROBLEM

As part of President Obama's European Phased Adaptive Approach (EPAA), the United States Navy will forward deploy AEGIS Ballistic Missile Defense (BMD) destroyers and cruisers to support the defense of Europe. Beginning in 2014, the Navy will forward deploy two AEGIS destroyers to Rota, Spain, followed by two more in 2015. The AEGIS weapon system deployed on destroyers and cruisers is a vital element of the missile defense shield that protects Europe, but the system requires regular maintenance and replacement parts. In an operationally demanding environment, ships need ready access to replacement parts, yet the cost of these parts must be balanced with the current fiscally constrained environment. However, BMD ships stationed in Sixth Fleet and the Mediterranean Sea face a number of short- and long-term constraints and challenges.

Operating in the Mediterranean Sea presents many unique challenges to deployed ships. Sixth Fleet and operational units must overcome the "last tactical mile," which incorporates the transfer of parts and supplies from shore-based warehouses or facilities to ships underway or in port. Since the end of the Cold War and President Obama's strategic pivot to the Pacific Area of Responsibility (AOR), the number of Navy assets stationed and deployed in Sixth Fleet has decreased, making it more difficult to transfer critical parts from shore to ship. Additionally, BMD destroyers and cruisers usually deploy independent of a carrier strike group or expeditionary strike group, reducing the logistics network available in the Mediterranean Sea.

The largest hurdle to overcome the last tactical mile is the limitation of shore- and sea-based helicopters and aircraft to transfer critical parts and supplies from shore-based supply centers to ships conducting BMD operations at sea. Flight I and II Arleigh Burke–class destroyers do not have the capability to deploy with organic helicopters but can receive and refuel helicopters.

Additionally, carrier strike groups and expeditionary strike groups, which normally transit the Mediterranean Sea en route to Fifth Fleet, do not operate regularly in Sixth Fleet and cannot contribute helicopters to assist in logistics operations. Two helicopters operate out of Naval Air Station Sigonella, but these helicopters are limited by their range so they cannot always deliver parts to BMD ships underway in the eastern Mediterranean Sea. To compensate for the range limitation, military logistics aircraft located at Naval Air Station Sigonella transfer parts between logistics hubs to decrease the last tactical mile.

Finally, long-term demand for AEGIS and BMD replacement parts will grow because the Navy intends to increase the number of its BMD-capable ships from 28 to 41. Furthermore, the addition of two AEGIS Ashore sites in Poland in 2015 and Romania in 2018 will increase the demand for BMD-related parts. The logistics community will be challenged to ensure that all BMD-capable assets have the required spare parts to support mission requirements in a fiscally constrained environment.

B. ORGANIZATION

In a mission area where the costs of failure can be catastrophic, BMD ships deployed in Sixth Fleet must have access to the spare parts and materials required to fulfill their mission. This report analyzes BMD readiness issues unique to Sixth Fleet in order to inform decision-makers and recommend to them where and how many critical parts should be staged to best support the operational readiness of BMD ships on EPAA missions.

Chapter II provides background on the BMD mission in Europe, the Iranian threat, and the AEGIS Weapon System (AWS), and it also presents a brief discussion of the Arleigh Burke–class destroyers that will be stationed in Rota, Spain. Additionally, the chapter discusses EPAA and identifies key stakeholders who will benefit from increased BMD ship readiness. It is essential to understand the uniqueness and importance of the BMD and EPAA missions, the relevance of the threat, and AWS capabilities and limitations in order to understand the importance of overcoming and minimizing the last tactical mile.

Chapter III describes previous solutions applied in Fifth and Seventh Fleets, which have mature logistics networks to support the BMD mission and ships against Iranian and North Korean threats. Additionally, the chapter examines the logistics network that supports the primary mission of Trident submarines, which provide strategic and nuclear deterrence, a mission strategically similar to BMD’s.

Chapter IV focuses on the optimization model used to determine the best location of BMD spare parts. The model incorporates various constraints and variables to determine the optimal solution for pre-staging critical BMD parts.

Finally, Chapter V presents recommendations and findings to decision-makers to improve and optimize BMD readiness in Sixth Fleet.

II. BACKGROUND

A. MISSION OVERVIEW

BMD is the protection of the United States homeland, global allies, and forces stationed abroad against intercontinental, and also long-, medium-, and short-range missiles from nations with the capability and intent to use those weapons. The Missile Defense Agency (MDA), a separate agency within the Department of Defense (DoD), manages and coordinates BMD efforts across all services to create a fully linked, integrated, and layered BMD System (BMDS). As displayed in Figure 1, MDA, a research, development, and acquisition agency, coordinates Air Force space systems, Army Ground-Based Interceptors (GBI), and Navy sea-based systems, while working closely with combatant commanders (COCOMs) to ensure that the BMDS supports their requirements.

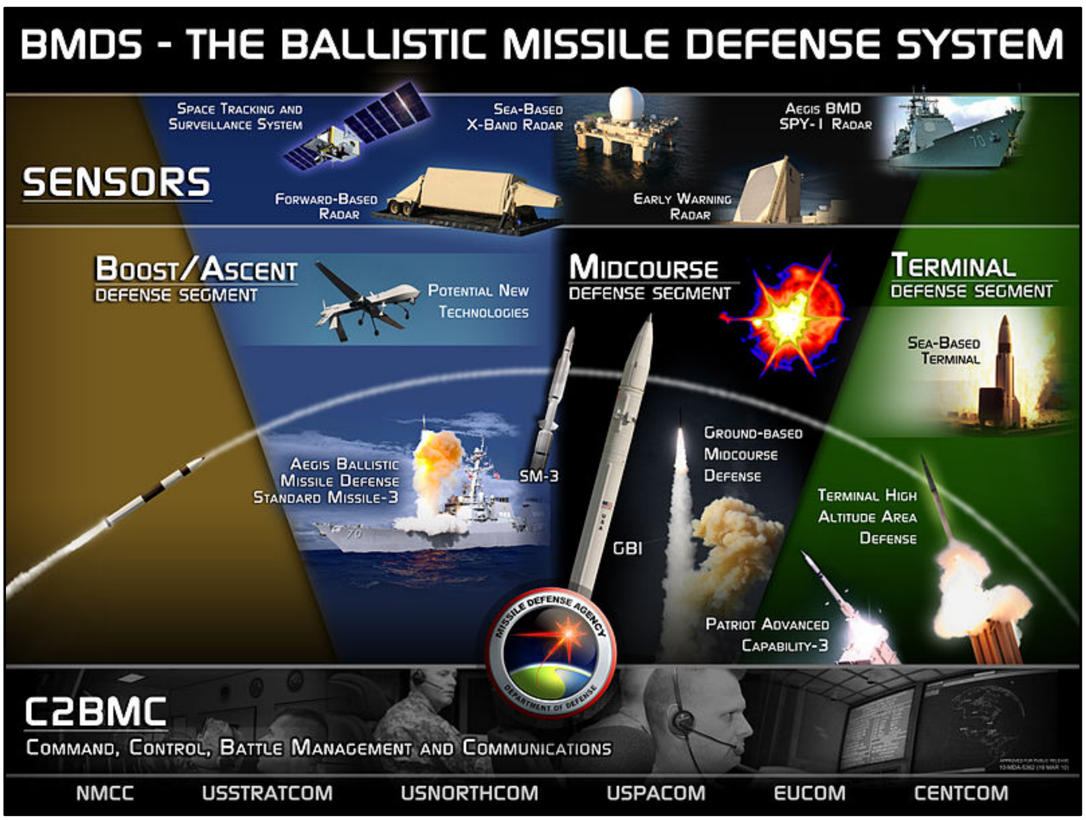

Figure 1. Ballistic Missile Defense System Overview
(Missile Defense Agency [MDA], n.d.)

B. IRANIAN THREAT

Iran presents a determined threat to the United States and its North Atlantic Treaty Organization (NATO) allies in the Middle East and Europe. Iran possesses

deployable medium-range ballistic missiles (MRBMs) that are inherently capable of carrying nuclear warheads and other weapons of mass destruction. Iranian MRBMs have ranges up to 2,000 kilometers, which are in striking distance of Israel, Turkey, and Greece, as displayed in Figure 2 (Hildreth, 2012, p. 22). Furthermore, intelligence assessments warn that Iran continues to pursue the development of intercontinental-range ballistic missiles (ICBMs) and could develop a weapon capable of reaching the United States homeland and its allies with foreign assistance (Hildreth, 2012, pp. 35–38).

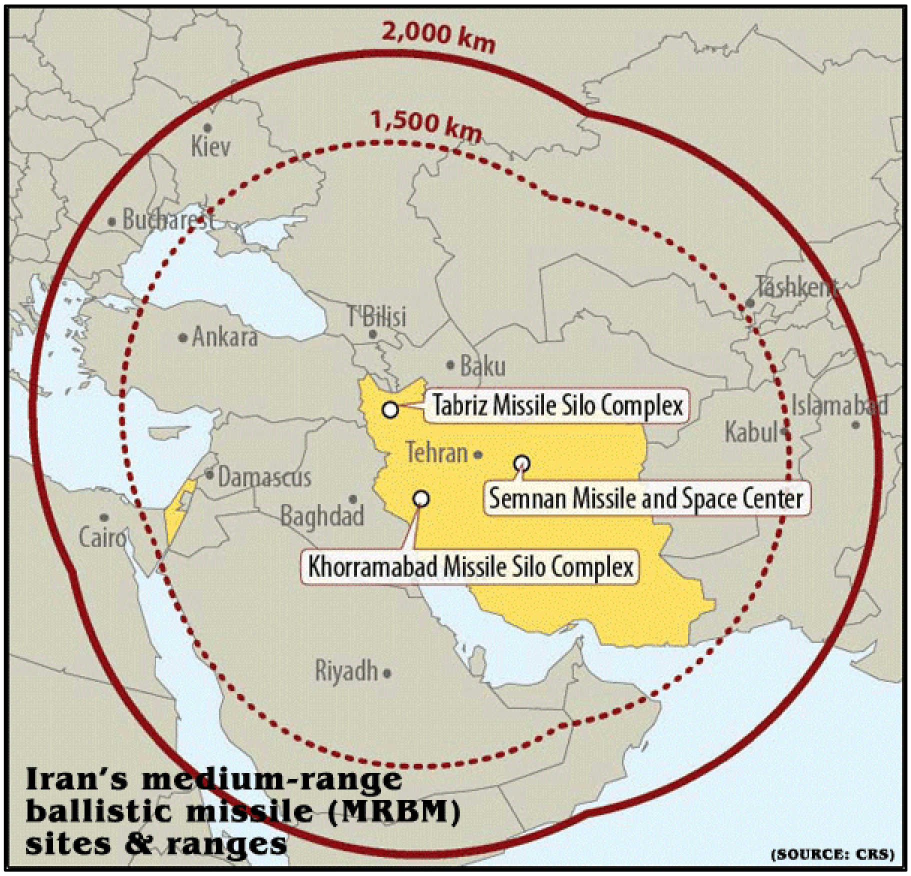

Figure 2. Range of Iranian MRBM
(Hildreth, 2012, p. 22)

C. NAVY'S ROLE IN BALLISTIC MISSILE DEFENSE

The Navy operates a variety of systems within the BMDS, but its main role is the application of sea-based sensors and sea-based engagement capability on AEGIS cruisers and destroyers. The Navy's BMD capability revolves around AWS employed on multi-mission cruisers and destroyers.

The Navy maintains 28 BMD-capable ships, five Ticonderoga-class Guided Missile Cruisers (CG), and 23 Arleigh Burke–class Guided Missile Destroyers (DDG), which regularly deploy to Pacific Command (PACOM), European Command

(EUCOM), and Central Command (CENTCOM) Areas of Responsibility (AOR) to support COCOMs against evolving regional and global threats. As ICBM technologies evolve and their ranges increase, COCOMs' demand for BMD-capable AEGIS ships exceeds the available supply. As former Chief of Naval Operations Admiral Gary Roughead stated, "Ballistic missile defense is going to be a core mission in the United States Navy and we are seeing that capability and capacity in greater demand than we ever have before" (MDA, n.d.). Under the proposed fiscal year (FY) 2014 budget, the number of BMD-capable ships is scheduled to grow to 41 ships by the end of FY2018.

Of the 28 BMD-capable ships, 16 are homeported in the Pacific, including five Forward-Deployed Naval Forces (FDNF) in Yokosuka, Japan; five in Pearl Harbor, HI; and six in San Diego, CA (MDA, n.d.). Additionally, 12 BMD ships are stationed in the Atlantic, with 10 in Norfolk, VA, and two in Mayport, FL. As part of EPAA, the United States Navy will station four BMD destroyers in Rota, Spain, to support BMD requirements. Additionally, the Navy will build and operate one AEGIS Ashore station in Romania and one in Poland to support BMD requirements in 2015 and 2018, respectively.

1. AEGIS Weapon System Overview

AWS is an integrated combat system developed to support multiple missions, including Anti-Air Warfare (AAW) and BMD. It consists of several integrated elements: AN/SPY-1D Phased Array Radar, MK-41 Vertical Launching System, MK-1 Weapon Control System, MK-1 Fire Control System, MK-1 Command and Decision System, AEGIS Display System, and MK-1 Operational Readiness Testing System. All of the elements contribute to the successful operation of the system as a whole to complete its mission, primarily AAW and BMD.

In addition to AWS, various communication and Tactical Digital Information Link systems are vital to the layered BMDS. Army, Navy, Air Force, and allied units use extremely high frequency and super high frequency links and communication systems to pass track information, prompt different tracking sensors, and cue engagements.

While AWS is a complex system, engineers designed multiple redundancies within each element of AWS to ensure maximum system readiness and eliminate a single point of failure within the system. However, when operating in BMD mode, AEGIS cruisers and destroyers transmit a great deal of power through the AN/SPY-1D Phased Array Radar, which stresses the system and periodically requires the replacement of critical parts. Therefore, a majority of AWS casualty reports (CASREPs) relate to the AN/SPY-1D, the sea-based sensor critical in the layered BMDS. Due to the nature of the BMD mission and ramifications of its failure, AWS

must operate continuously to support COCOM mission requirements. Thus, critical parts and spares need to be on hand or readily accessible to minimize AWS downtime.

2. Arleigh Burke Flight I and II Destroyers

The four ships selected for forward deployment in Rota are Arleigh Burke–class destroyers. USS *Carney* (DDG-64) and USS *Ross* (DDG-71) are classified as Flight I Arleigh Burke–class destroyers, and USS *Donald Cook* (DDG-75) and USS *Porter* (DDG-78) are classified as Flight II Arleigh Burke–class destroyers. All four ships have similar AWS employed onboard and common AEGIS baselines configured for BMD, with minor AEGIS Combat System (ACS) differences. Thus, all required AWS parts are interchangeable for BMD.

Flight I and Flight II destroyers have the capacity to land and refuel helicopters but do not have the organic capability to deploy with an embarked helicopter detachment. Thus, Flight I and Flight II destroyers can only receive supplies from inorganic or shore-based helicopters, from supply ships during an underway replenishment, or by pulling into port.

3. Overview of BMD Casualty Reporting Procedures

Any casualty or degradation to an individual AWS element can contribute to a degradation of the system as a whole. Casualties that contribute to a minor degradation of a primary or secondary mission area are classified as Category (CAT) 2 CASREPs, those that contribute to a major degradation of a mission area are classified as CAT 3 CASREPs, and those that contribute to a loss of a mission area are classified as CAT 4 CASREPs.

D. EUROPEAN PHASED ADAPTIVE APPROACH

The Obama Administration revealed a new strategy for European BMD on September 17, 2009, that incorporated a phased adaptive approach. Each phase of the adaptive approach brings increased DoD ballistic defense capability to the European theater, which is collectively known as EPAA. EPAA replaced the previous European missile defense program that called for a fixed interceptor site in Poland and a fixed radar site in the Czech Republic (Government Accountability Office [GAO], 2011, p. 1).

The new European regional approach to BMD requires AEGIS BMD ships, AEGIS shore-based sites, and upgraded land-based radar to protect European allies against short- and medium-range ballistic missile threats. The phased approach also addresses future long-range missiles and other developing missile threats, particularly from Iran. The MDA outlined the four phases specific to EPAA:

- **Phase I:** Deploying existing AEGIS BMD ships with Standard Missile-3 interceptors (SM-3 Block 1A) and a land-based radar (AN/TPY-2) in Europe by the end of 2011 (GAO, 2011, p. 4). This phase was successfully completed on March 7, 2011, with the Mediterranean Sea deployment of an AEGIS BMD ship based out of Norfolk, VA, as part of EPAA.
- **Phase II**: Field-enhanced capability to defend against short- and medium-range ballistic missiles by including a land-based version of the AEGIS BMD weapon system in Romania with an upgraded SM-3 Block 1B interceptor by 2015 (GAO, 2011, p. 4).
- **Phase III**: Field-enhanced capability to defend against short- and medium-range ballistic missiles by including an AEGIS Ashore in Poland with an advanced SM-3 Block IIA interceptor by 2018 (GAO, 2011, p. 4).
- **Phase IV**: Field-enhanced capability to defend against longer range threats, including intercontinental ballistic missiles, by including an upgraded SM-3 Block IIB interceptor (GAO, 2011, p. 4).

On March 15, 2013, Secretary of Defense Chuck Hagel announced significant changes to EPAA. Due to program delays for the advanced SM-3 Block IIB interceptor and cuts in congressional funding, the DoD cancelled Phase IV of EPAA and reallocated the funds to enhance GBI programs.

1. Forward-Deployed BMD AEGIS Assets in Rota, Spain

NATO, Spain, and the United States concurrently announced on October 5, 2011, that four BMD AEGIS destroyers would be forward deployed to the naval base in Rota, Spain, in support of EPAA. The first two destroyers, USS *Ross* (DDG-71) and USS *Donald Cook* (DDG-75), will shift homeports to Rota in FY2014. During FY2015, USS *Carney* (DDG-64) and USS *Porter* (DDG-78) will shift homeports to Rota. Three of the four destroyers were originally homeported in Naval Station Norfolk, VA, and the fourth, USS *Carney* (DDG-75), was stationed out of Naval Station Mayport, FL.

At least one BMD-capable AEGIS ship is committed to patrol the eastern Mediterranean Sea, where its BMD capabilities will be most effective. Without a forward-stationed base in the European theater, approximately 10 BMD-capable ships would need to be in ready reserve from bases in Norfolk, VA, and Mayport, FL, to adequately cover the transit times and stationing requirements to fulfill EPAA (O'Rourke, 2013a, p. 60). The four destroyers will have more expedient access to the eastern Mediterranean Sea should the need for more than one BMD-capable

ship arise. The forward-deployed ships will also engage in joint operations with NATO allies in the region, including Standing NATO Maritime Groups, joint naval exercises, and maritime security cooperation functions (O'Rourke, 2013a, p. 56).

2. Key EPAA Stakeholders

Several DoD departments and agencies play a vital role in BMD and EPAA development and execution.

- **Under Secretary of Defense for Acquisition, Technology, and Logistics:** Ensures the policy guidance and development of missile defense strategy for MDA, including broad procurement objectives. The Under Secretary provides oversight for the funding plan for global BMD strategy.
- **Missile Defense Agency (MDA):** The primary BMD stakeholder is the MDA, which holds a variety of responsibilities ranging from research and acquisition of BMD elements to oversight of BMD requirements. MDA has a unique position regarding BMD development because it is exempted from the traditional requirements that other joint DoD agencies must abide by. These exemptions allow MDA to apportion BMD resources as needed while working closely with COCOMs to address current and future threats.
- **EUCOM**: The COCOM responsible for the European theater, including Turkey, Russia, and Israel, and the lead COCOM that executes and plans EPAA. EUCOM utilizes its military service components to field the assets necessary to implement EPAA.
- **Sixth Fleet:** The operational branch for U.S. Naval Forces Europe that conducts theater security cooperation missions and maritime operations in Europe. Sixth Fleet works along with NATO, interservice, and interagency components to provide naval assets and resources to execute EPAA. Assets provided by Sixth Fleet also include trained personnel and maintenance capability for combat systems.
- **Commander, Combined Task Force 63 (CTF 63):** The logistics branch of Sixth Fleet that is responsible for supply support of naval assets afloat in Europe, including naval assets operating for EPAA. CTF 63 is headquartered out of Naples, Italy, and consists of replenishment and repair ships that focus on delivering supplies and services at sea. CTF 63 is also responsible for procuring and tracking spare parts and supplies that are delivered to ships.

- **NATO**: Member nations of NATO are responsible for coordinating multinational military defense in the European theater, including joint maritime security operations. Member nations of NATO have a vested interested in the implementation of EPAA to counter regional threats such as Iran and Russia.

3. Naval Support Facilities in Sixth Fleet

Commander, U.S. Sixth Fleet is based and headquartered in Naples, Italy, to support EUCOM. However, many shore-based assets support ships deployed to the AOR. Figure 3 identifies the locations of major Navy logistical hubs around the Mediterranean Sea that support BMD missions.

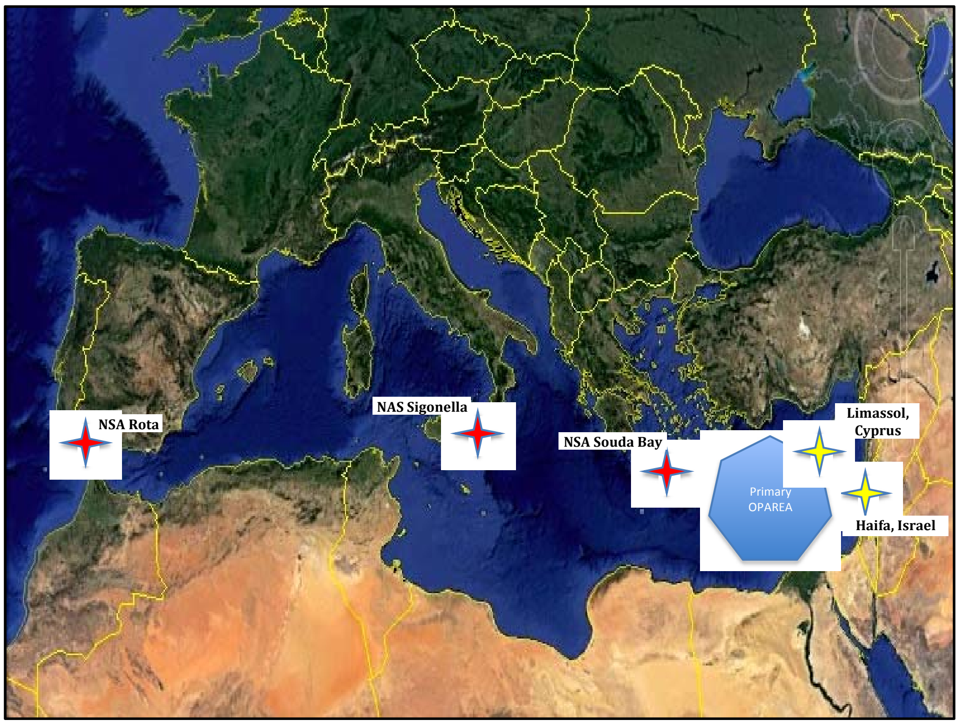

Figure 3. Map of Naval Support Facilities in Sixth Fleet That Support BMD
(Google Earth, n.d.)

- **Naval Base Rota:** The location of the naval base at Rota is crucial to the overall efficiency of EPAA. Rota is located in the southwestern Atlantic coast of Spain along the Bay of Cádiz, which is approximately 60 miles from the Strait of Gibraltar. Additional base infrastructure is being constructed to accommodate the four BMD-capable ships along with increased facilities maintenance capabilities. Naval Supply Systems Command (NAVSUP) Fleet Logistics Center (FLC) Rota provides logistics and support services to ships. NAVSUP FLC Rota

also serves as the entry and exit point for material from the United States via the East Coast.

- **Naval Air Station (NAS) Sigonella:** NAS Sigonella is located in eastern Sicily and provides administrative and logistical support to the United States and other NATO allies. The central location of NAS Sigonella in the Mediterranean Sea gives it a strategic geographic advantage. In January 2005, Fleet and Industrial Supply Center (FISC) Sigonella (which became NAVSUP FLC Sigonella in 2011) was established to provide logistical support and procurement for forces operating in Sixth Fleet and is the main logistics hub in the Mediterranean theater. NAVSUP FLC Sigonella and NAVSUP FLC Sigonella Detachment Naples are responsible for providing theater-wide logistics support, including the oversight of the logistic support centers located in Rota, Naples, and Souda Bay.
- **Naval Support Activity (NSA) Souda Bay:** NSA Souda Bay is located in the northwest coast of Crete in the Greek isles. NAVSUP FLC Souda Bay provides forward logistical support to the United States and other NATO allies operating in the eastern Mediterranean Sea.
- **Haifa, Israel:** Located on the Mediterranean coast of Israel, Haifa is utilized as a port of call for U.S. and NATO ships operating in the eastern Mediterranean Sea. Critical materiel and parts that are commercially shipped to ships in the eastern Mediterranean Sea often arrive in Israel.
- **Military Sealift Command (MSC):** MSC assets that operate in Sixth Fleet typically include Kaiser-class supply ships that perform rotational duties in the Mediterranean Sea. MSC assets provide underway replenishment capabilities, including parts delivery, to U.S. and NATO ships operating in Sixth Fleet.

III. PREVIOUS AND PROPOSED SOLUTIONS

AEGIS BMD ships regularly deploy to Fifth and Seventh Fleet AORs, and a robust logistics network exists to support their missions. Additionally, Trident ballistic missile submarines fulfill a similar strategic mission. In this chapter, we briefly analyze the Trident System's logistics support. Finally, we examine Sixth Fleet's current logistics network that supports BMD ships.

A. SEVENTH FLEET

Five AEGIS BMD ships are stationed in Yokosuka, Japan, as part of the FDNF to support the Commander, U.S. Seventh Fleet against North Korean threats. These ships include one cruiser, which serves as the BMD mission commander for Commander, Carrier Strike Group Five, in addition to four destroyers assigned to Commander, Destroyer Squadron Fifteen. FDNF ships have regularly responded to BMD operations when tensions escalate with North Korea. On April 5, 2009, USS *Stethem* (DDG 63), USS *Curtis Wilbur* (DDG 54), USS *Fitzgerald* (DDG 62), and USS *Shiloh* (CG 67) successfully tracked the North Korean Taepodong-2 missile fired over Japan (Roughead, 2009, p. 6; Sang-Hun & Sanger, 2009). Additionally, BMD ships stationed in Pearl Harbor, HI, and San Diego, CA, regularly deploy to Seventh Fleet to support BMD.

Logistically, a mature network, led by Defense Logistics Agency (DLA) Distribution Yokosuka and NAVSUP FLC Yokosuka, provides distribution support throughout the Western Pacific Ocean and Indian Ocean. It also provides logistics support to warships of the carrier strike group homeported in Yokosuka, the expeditionary strike group homeported in Sasebo, and U.S. naval vessels transiting the Seventh Fleet AOR (DLA, n.d.).

In addition to a robust logistics network, FDNF ships have ready access to shore- and sea-based aircraft to transfer mission-critical BMD parts and minimize the downtime caused by the last tactical mile. In addition to shore-based helicopters in Japan and South Korea, including Japanese Self-Defense Force (JSDF) assets, Carrier Strike Group Five, Expeditionary Strike Group Seven, and multiple Combat Logistics Force (CLF) ships regularly operate in theater and give BMD ships ready access to critical parts, if required. A unique aspect of the BMD mission is the partnership with the JSDF in the BMD mission area, because the Japanese operate BMD ships and shore-based assets of their own. The JSFD agreed to support the U.S. BMD ships by transferring parts to U.S. BMD ships at sea on JSDF helicopters and allowing U.S. helicopters to refuel at JSDF bases.

B. FIFTH FLEET

BMD ships regularly deploy to the Fifth Fleet AOR to support the Commander, Fifth Fleet and the Commander, CENTCOM against Iranian ballistic missile threats. The Arabian Gulf is a smaller area than the eastern Mediterranean Sea or Pacific Ocean, and many shore- and sea-based assets operate regularly to support ships at sea. NSA Bahrain serves as the central hub to deliver parts to ships throughout the Arabian Gulf. Additionally, DLA Distribution Bahrain and NAVSUP FLC Sigonella's Bahrain Detachment support ships deployed to the Fifth Fleet AOR.

Normally, a carrier strike group and multiple CLF ships operate in the Fifth Fleet AOR to provide helicopters to transfer critical parts to BMD ships underway. Additionally, shore-based helicopters and other logistics aircraft are forward deployed in Bahrain to provide continuous logistics support in the Arabian Gulf. Collectively, these minimize the last tactical mile to deliver critical parts to ships operating in the Arabian Gulf.

C. TRIDENT SUBMARINES

Ballistic missile submarines fulfill a similar mission to BMD AEGIS ships, and in this report, we briefly compare the different logistics networks that support two different assets with equally important missions. The Navy operates four nuclear-powered cruise-missile submarines (SSGNs) and 14 nuclear-powered ballistic-missile submarines (SSBNs) that perform a variety of missions. SSGNs carry Tomahawk cruise missiles and provide covert strike capability for COCOMs; they do not carry nuclear weapons.

SSBNs are armed with submarine-launched ballistic missiles (SLBMs), which are large, long-range missiles armed with multiple nuclear warheads. The SSBNs' primary mission is to remain hidden at sea using their SLBMs to deter a nuclear attack on the United States by another country; this demonstrates to other countries that the United States has an assured second-strike capability against any nuclear attack (O'Rourke, 2013b, p. 2). SSBNs fulfill a vital mission forming one leg of the U.S. strategic nuclear deterrent force, which also includes land-based ICBMs and land-based long-range bombers (O'Rourke, 2013b, p. 2).

SSGNs and SSBNs normally deploy for long periods of time, have limited space to store spare parts and supplies, and have limited access to sea- and shore-based logistics networks because they remain submerged to covertly conduct their mission. While the Trident System deployed on SSGNs and SSBNs provides strategic offensive capability, the defensive capability that AEGIS BMD ships provide is equally important.

To support SSGNs and SSBNs, Burke's (2012) *Logistics Support of the Trident System* outlined specific requirements to sustain the strategic assets during their deployments. Models used historical and predicted Trident program usage data to compute the shipboard allowance and load lists (Burke, 2012, p. 8). This optimal coordinated shipboard allowance list (COSAL) is designed to ensure that an SSBN has enough replacement parts for preventative and corrective maintenance to perform its core mission for a period not to exceed 90 days. As outlined in *Logistics Support of the Trident System*, the depth of the on-hand inventory of repair parts is provided to ensure

- 99.99% average protection against probability of stock out for items that, if not available, would cause total missile launch degradation or termination of patrol;
- 99% average protection against probability of stock out for items that, if not available, would partially degrade the missile launch capability; and
- 90% average protection against probability of stock out for all other items (Burke, 2012).

Thus, SSBNs and SSGNs are provisioned with enough parts to provide protection against the probability of stock out of the equivalent of CAT 3 and CAT 4 CASREPs to complete a mission up to 90 days in length. A great deal of planning, research, and modeling goes into the COSAL planning to support the Trident System's strategic mission.

Furthermore, the DoD uses Force/Activity Designators (F/AD) to define the relative importance of military forces and delineate a hierarchy of priorities used in supply requisitions (Loose, 2009, p. 6). Assigned by the Secretary of Defense and Chairman, Joint Chiefs of Staff, F/AD I designators are assigned to top national priorities and strategic systems. Trident SSBNs are designated F/AD I, the highest designation, and SSGNs are designated F/AD II, the second highest designation (Burke, 2012, p. 13). Additionally, BMD ships, strategic assets with a critical mission comparable to SSBNs, are assigned F/AD I (Commander, CTF 63, 2013a, p. 28).

As strategic assets, should AEGIS BMD ships be equipped with enough COSAL to provide 99.99% and 99% protection against CAT 3 and CAT 4 CASREPs? This report analyzes aspects of this problem through modeling to make recommendations to decision-makers.

D. SIXTH FLEET

BMD ships normally deploy independent of a carrier strike group to support the Commander, Sixth Fleet in the eastern Mediterranean Sea against Iranian

MRBM threats. Navy ships have regularly deployed to the region, and a robust logistics network supports ships operating in the AOR.

1. Combined Task Force 63 Roles and Responsibilities

CTF 63 is responsible for "coordinating and providing transportation and delivery of personnel, equipment, fuel, supplies, repair parts, mail, and ammunition via air and surface logistics assets—including MSC combat logistics force ships—to sustain U.S. forces in the European and African theaters" (Henderson, 2013). Realizing the importance of the BMD mission, CTF 63 (Commander, CTF 63, 2013a) outlined a number of processes in its *CTF 63 Logistics Handbook: Procedures for SIXTHFLT AOR* to support BMD casualties.

CTF 63 directs the movement of all BMD CASREP material and maintenance personnel to BMD ships in port and underway in the Mediterranean Sea. Replacement parts for CAT 2 CASREPs are transferred in theater via commercial means or military aircraft (MILAIR) and delivered to the ship during port visits or replenishment-at-sea (RAS) evolutions by CLF. CTF 63 explores additional means to quickly deliver CAT 3 and CAT 4 CASREP material and maintenance personnel to BMD ships underway. Naval Air Station Sigonella serves as the primary logistics hub for Sixth Fleet, but BMD ships can also pick up parts in Souda Bay, Crete; Haifa, Israel; and Rota, Spain, during port visits.

2. Logistics Overview

Intra-theater transportation of air cargo is coordinated by CTF 63 after considering unit schedules and utilizing MILAIR, Air Mobility Command (AMC) channel services, and commercial air. Air-shipped large cargo (over 300 pounds) sent to/from units operating within the AOR are normally transported to/from the continental United States (CONUS) by AMC airlift to/from Naval Air Terminal (NAVAIRTERM) Rota, NAVAIRTERM Sigonella, or NAVAIRTERM Djibouti based on routing guidance contained in the cargo routing information file (Commander, CTF 63, 2013a, p. 6).

All Navy material shipments under 300 pounds are typically shipped via commercial shipper (e.g., FedEx, DHL, UPS). In most cases, the material is shipped via one of the Navy's logistics hubs—in Rota, Naples, Sigonella, Souda Bay, or Djibouti (as displayed in Figure 4)—for further transfer to the ship via Navy transport. In some cases, delivery directly to the ship can occur. The Sixth Fleet AOR does not have vertical onboard delivery capability and has no organic helicopters assigned.

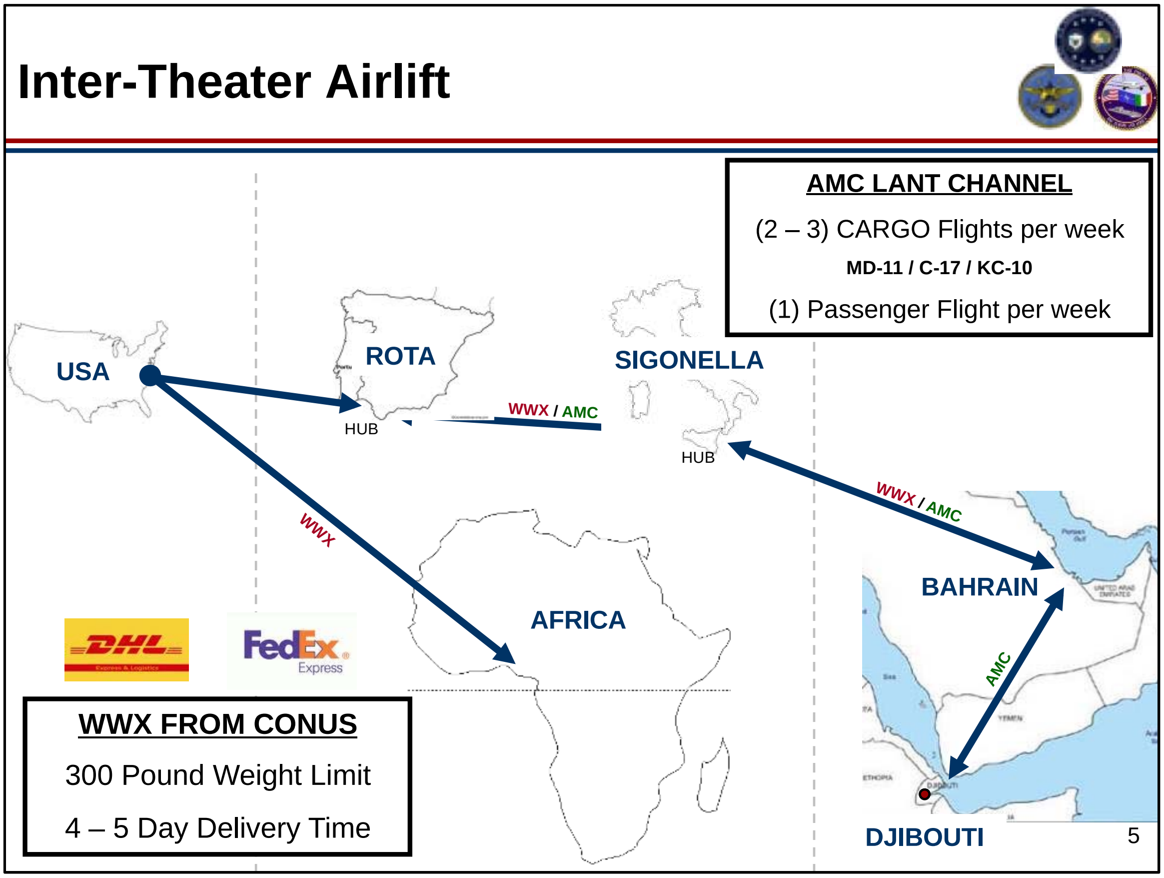

Figure 4. Sixth Fleet Logistics Hubs
(Commander, CTF 63, 2013b, p. 5)

3. BMD Casualty Reporting Procedures

Recognizing the importance of the BMD mission, Sixth Fleet puts a high priority on speed and coordination in moving CAT 3 and 4 CASREP materiel to meet BMD ship emergent logistics and maintenance requirements. CTF 63 coordinates with the Sixth Fleet maintenance officer in monitoring shipboard CASREPs and moving required repair parts and personnel to meet ship repair requirements. CTF 63 has specific procedures outlined in its *CTF 63 Logistics Handbook: Procedures for SIXTHFLT AOR* (Commander, CTF 63, 2013a) to support BMD ships during increased BMD posture levels and CAT 3 and CAT 4 CASREPs. Listed are the main contingency procedures CTF 63 uses to support ships during BMD missions as described in *CTF 63 Logistics Handbook: Procedures for SIXTHFLT AOR*:

- Shuttle CLF to the BMD operating area to support and maximize scheduled underway replenishments (UNREPs) to receive parts and fuel to increase the ship's endurance. This is the primary delivery option when Sixth Fleet directs a BMD ship to remain on station and the ship does not have an embarked helicopter.

- Transfer material from CONUS or DLA Distribution Sigonella to a commercial airport nearest the ship, and complete final delivery to the ship via CLF, the ship's representative in port, the ship's embarked helicopter, or a rigid hull inflatable boat (RHIB) at sea.
- Transfer the material via a Norfolk Ship Support Activity maintenance team member for hand-carrying on a commercial flight to a commercial airport nearest the ship, and complete final delivery to the ship via CLF, the ship's representative in port, the ship's embarked helicopter, or an RHIB at sea.

Additionally, for BMD ships operating in the eastern Mediterranean, BMD material is sent through commercial channels to Tel Aviv, Israel, and transported to the unit during a port of call at Haifa, Israel. BMD material shipped through military logistics capabilities is processed through MILAIR or AMC channels to Sigonella and then transferred via CLF ship to the unit or airlifted to NSA Souda Bay. An overview of BMD logistics distribution processes is displayed in Figure 5.

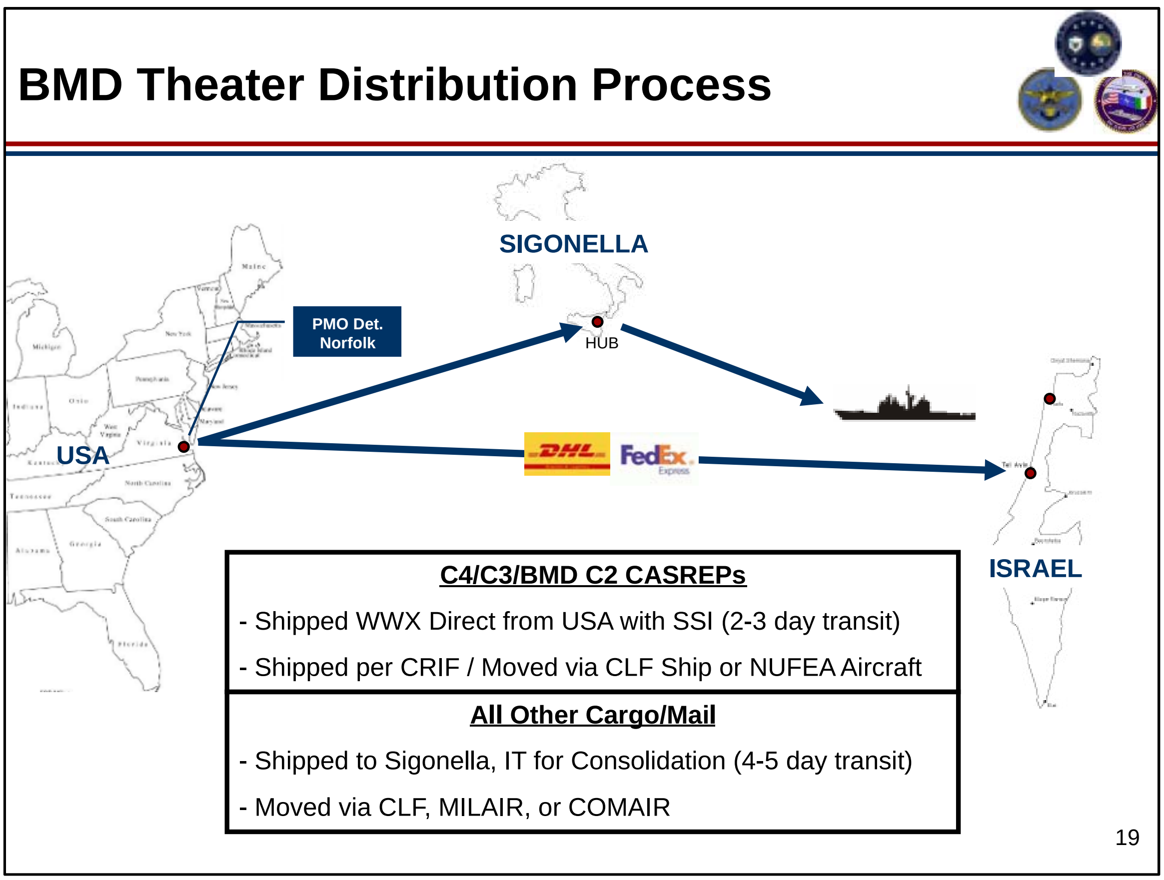

Figure 5. BMD Logistics Process
(Commander, CTF 63, 2013b, p. 19)

4. BMD Pack-Up Kits

BMD pack-up kits (PUKs) originally consisted of 30–34 critical spares that were rotated between deploying BMD ships. In 2011, NAVSUP Weapon Systems Support (WSS) determined that PUK parts should be placed on every BMD ship, regardless of deployment status. As a result, a custom-made allowance parts list was developed for each ship's COSAL. Commander, Naval Surface Forces Atlantic closely monitors these parts and treats them as if they were a PUK, even though BMD ships do not transfer the parts among themselves.

5. Sixth Fleet Forward-Positioned BMD Parts

Continuous BMD missions in the eastern Mediterranean created a need for forward-staged parts to accommodate high demand rates. In 2011, NAVSUP Global Logistics Support (GLS) and WSS analyzed specific BMD national item identification numbers (NIINs) based on demand history, criticality of parts, CASREP requisitions, and operational availability (J. W. Camuso, personal communication, July 19, 2013). Based on the results of the analysis, a forward-positioned parts plan was constructed. Three groups of parts were identified for forward-stock positioning in theater to support FDNF BMD ships:

- BMD-specific parts: A collection of 270 NIINs specific to BMD shipboard systems was identified and subsequently positioned in theater at Defense Distribution Depot Sigonella (DDSI; J. W. Camuso, personal communication, July 19, 2013). DDSI personnel closely monitor the parts and inventory levels. The demand from BMD ships in theater since the inception of the program has been moderately high.
- BMD operational-level (O-level) parts: Parts that are not specifically used on BMD systems but are used to provide supplemental maintenance support to ship systems in Rota. There are approximately 800–900 parts identified, but a validation process is still underway. O-level parts are stocked at DDSI.
- "Forward 8": There are eight high-usage, high-dollar-value, critical BMD/SPY radar parts stationed in theater at DLA Distribution Sigonella for the specific use of Sixth Fleet ships. NAVSUP WSS determined this requirement in late 2010 (J. W. Camuso, personal communication, July 19, 2013). The parts are managed by DDSI, and daily reports are submitted on the status of these critical parts to several Sixth Fleet entities. The Forward 8 parts are listed and described in Table 1.

Table 1. List of Forward 8 Parts
(NAVSUP Type Commander, 2013)

Forward 8 Parts				
Nomenclature	**NSN**	**NIIN**	**Cost**	**Location**
Electronic Switch	5840012584120	12584120	$226,967	DDSI
Electronic Switch	5840012584121	12584121	$292,295	DDSI
Filter, Radio Frequency Interference	5915014657505	14657505	$26,844	DDSI
Rectifier Network	5965014657503	14657503	$118,433	DDSI
Power Supply	6130012583679	12583679	$173,622	DDSI
Inverter, Power	6130014657498	14657498	$104,863	DDSI
Power Supply	6130014824403	14824403	$63,092	DDSI
Simulator Group	6940012583671	12583671	$227,971	DDSI

E. LONG-TERM BMD AEGIS COST CONSTRAINTS

Many factors affect AEGIS supply readiness, including economic constraints that limit the supply side of part production in addition to the costs of pre-positioning assets. The balance between parts availability and operating under fiscal constraints must be analyzed to optimize readiness. The reduction of available funds to support spare parts and parts availability has made it harder to achieve acceptable readiness levels. However, as critical spare parts become difficult to obtain, the ability to sustain BMD operations at sea becomes hindered. In a cost-constrained environment, it is imperative to optimize supply funding, placement, and policies to maintain appropriate readiness levels.

The regional, flexible approach to BMD, as in EPAA, encounters uncertain life-cycle costs. This uncertainty stems from the evolving approach of EPAA, which recognizes that a strategic approach does not have the same clear objectives and limitations as a detailed defense program. Proper life-cycle cost calculations would show the impact on the supply chain and also all other costs, ranging from research and development, production, operations, and maintenance. Even though the EPAA makes the future infrastructure and policies more predictable, sufficient cost-estimation models also exist to estimate costs and efficiently budget and appropriate funds for current and future use. Without considering long-term cost estimations, supply sparing and BMD mission readiness in the Mediterranean Sea may be adversely impacted.

F. SCOPE

In developing a model to optimize BMD readiness, this report develops a mathematical approach to improve the current forward staging of critical BMD spare parts. This project places an emphasis on the Forward 8 critical spares that are

located in Sigonella in order to minimize overall lead times involved in getting these high-demand parts to operational BMD ships. In this report, we analyze an optimum staging strategy that would maximize the operational readiness of BMD ships while they are on station in the eastern Mediterranean.

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IV. OPTIMIZATION MODEL

The previous three chapters discussed the importance of analyzing the Forward 8 parts to improve BMD readiness in Sixth Fleet. This chapter focuses on the technique and model we used to optimize BMD logistics support for BMD ships operating in Sixth Fleet.

A. DATA SOURCES

1. Sixth Fleet CASREP Data

We analyzed CAT 3 and 4 CASREP data from January 2011 through August 2013 provided by CTF 63. Evaluating all CGs, DDGs, and Oliver Hazard Perry–class frigates that deployed to the Sixth Fleet AOR, we derived the average transit time and customer wait time for ships to receive CAT 3 and 4 CASREP materials related to ship systems at a specific port. Transit time is based on the transportation time a part takes to get from a shipping node to the ship. Customer wait time incorporates transit time and the administrative processing time between when a requisition is placed to when it is sent. The results are listed in Table 2.

Table 2. Consolidated CASREP Data From CTF 63

Location	CASREPS	Average Transit Time (days)	Average Customer Wait Time (days)
All	1,132	9	13
Rota, Spain	100	8	11
Haifa, Israel	107	7	10
Sigonella, Italy	403	10	15
Limassol, Cyprus	10	9	12
Souda Bay, Crete	259	6	8

The data in Table 2 illustrate the time delay in routing mission-critical parts from logistics hubs to ships underway around the Mediterranean Sea. We assumed all CAT 3 and 4 materials are given equal shipping priority, and made no distinction between AEGIS BMD parts, AEGIS parts, and non-AEGIS parts (i.e., engineering materials). This provided us with a larger data set to evaluate overall transit times in the region rather than if we had focused solely on AEGIS parts. Minimizing CASREP lead times is given the highest weight in the model as it directly relates to minimizing the last tactical mile to deliver critical parts to BMD ships.

2. COMAIR Data

To determine the availability of COMAIR in the AOR, we examined the frequency and proximity of commercial air transportation flights to Sixth Fleet logistics hubs. We evaluated transportation data from FedEx and DHL commercial websites, as they are two of the primary companies that transfer materials for the Navy in the AOR. Additionally, we evaluated the distance from the COMAIR office to the military logistic hub using FedEx and DHL commercial websites.

3. MILAIR Data

To determine the availability of MILAIR, we contacted DESRON 60 and CTF 63 staff members to determine the availability of military assets in the AOR.

4. Proximity Data

To determine the proximity data, we measured the distance between a logistics hub to the estimated OPAREA using Google Maps as displayed in Figure 4.

B. LOGISTICS FACTORS

We examined multiple logistics factors that contribute to the delivery time of CASREP material in Sixth Fleet. Within the model, we quantified the efficiency of each logistics factor, including staging parts on the ship, in relation to specific logistic hubs.

1. Access and Availability of Military Sealift Command (MSC) Assets

CLF ships are a vital resource to transfer parts from a logistics hub to a ship underway. Although transit times of a part generally increase when a CLF ship is used, the ability of the BMD ship to remain on-station has several mission-enhancing advantages. Each logistics hub is given a score based on the volume of outbound replenishments CLF ships conducted during the past two years from each port.

2. Access and Availability of Military Aircraft (MILAIR)

MILAIR is one method used to transport material throughout Sixth Fleet AOR and provides distinct advantages. If a logistics hub with forward-staged parts has access to MILAIR, air transport times can be minimized. MILAIR also provides the only air transportation option to deliver material directly to a ship underway, which is imperative since BMD ships do not possess organic helicopters. Most customs regulations from regional host nations are also bypassed when using MILAIR. Each logistics hub is scored based on the quantity and type of MILAIR, such as fixed- and rotary- wing squadrons. MILAIR factors also incorporate airfields on military installations as well as the volume of air traffic to other hubs in the region.

3. Access and Availability of Commercial Aircraft

COMAIR are widely used to expedite critical parts from logistics hubs to nearby ports ships can pull into. Often, COMAIR provide the shortest transit times. Major carriers, such as FedEx and DHL, are used to transport parts using the most expedient service category available. COMAIR benefits include frequent international transit routes and interactive features, such as online shipment tracking. Access to COMAIR is evaluated based on the number of commercial flights per week by different major carriers near each logistics hub.

4. Proximity to Operating Area

Geographic proximity between a logistics hub and a ship is a crucial factor in evaluating lead times. Typically, transit lead times are decreased the closer a logistics hub is to the operating area (OPAREA). BMD missions are normally conducted in a general OPAREA in the eastern Mediterranean as displayed in Figure 4. Logistics hubs are assigned scores based on their proximity to the OPAREA.

5. Transferability of Parts

Logistics hubs that have accessibility to several modes of transportation are vital if critical parts will be staged there. Not only is it important to transfer parts from the logistics hub to the BMD ship, but it is equally important to have the capability to transfer parts from one logistics hub to another. Demand will not always be from a BMD ship in the OPAREA as logistics hubs that maintain the inventory of parts must have the capacity and capability to transfer parts to other areas. Transferability refers to the degree that forward-staged parts can move from one logistics hub to another. Access to MILAIR, COMAIR, MSC assets, and military installations is factored into the transferability rating of a logistics hub.

6. Demand

Demand rates of Forward 8 parts were analyzed using the Web Visual Logistics Information Processing System to determine which logistics hubs received parts over a two-year period. Scores for each logistics hub were assigned based on the quantity of parts received at that location.

C. METHODOLOGY

This model is constructed as an integer program that addresses the optimal forward-staging locations of Forward 8 parts throughout Sixth Fleet. After analyzing several variables using a Solver add-in, we constructed an optimization model in Microsoft Excel. This model assigns scores to logistics hub and NIIN-specific categories that affect the last tactical mile of parts delivery. Logistics hubs are given

efficiency scores based on average CASREP part transit times and availability of MSC assets, COMMAIR, and MILAIR. Proximity of the logistics hubs to the OPAREA and transferability of parts between hubs are also incorporated into this model. Forward 8 parts demand rates are analyzed for each hub. Since CASREP lead time is used as a category, a low score is deemed as favorable and a high score is deemed as unfavorable. As a last step, weighted factors are assigned to each category to differentiate their relative importance.

D. MODEL FORMULATION

This section outlines the model formulation and all relevant indices, variables, and parameters. The objective function examines the combination of logistics categories, efficiency scores, and weighted factors that yield the lowest score. Since the model allows users to change the weighting scheme according to relative importance, the objective function combines all the various scores, weights, and categories to produce one overall efficiency score for each location. The objective function is minimized because lead times are used as a logistics factor and reduction of lead times is seen as a benefit. Therefore, the solution with the lowest score will be the optimal solution. The output of the entire model will select the optimal location for Forward 8 parts in Sixth Fleet to support BMD ships operating in the region based on minimized scores.

Indices

i NIIN part

j logistics hub

e efficiency score

w weighted factor

Decision Variables

X_{ij} = number of parts i to place in location j

Parameters

CAS_w = CASREP transit time weighted factor w

CAS_{ej} = Average CASREP transit time efficiency score e at location j

MSC_w = Availability of MSC assets weighted factor w

MSC_{ej} = Availability of MSC assets efficiency score e at location j

MIL_w = Availability of MILAIR weighted factor w

MIL_{ej} = Availability of MILAR efficiency score e at location j

COM_w = Availability of COMAIR weighted factor w

COM_{ej} = Availability of COMAIR efficiency score *e* at location *j*

$PROX_w$ = Proximity to OPAREA weighted factor *w*

$PROX_{ej}$ = Proximity to OPAREA efficiency score *e* at location *j*

$TRANS_w$ = Transferability weighted factor *w*

$TRANS_{ej}$ = Transferability efficiency score *e* at location *j*

DEM_w = Demand weighted factor *w*

DEM_{eij} = Demand efficiency score e of part *i* at location *j*

E. FORMULATION

The objective function is to minimize weighted efficiency scores:

$$\sum_j CAS_w * CAS_{ej} \sum_i X_{ij} + \sum_j MSC_w * MSC_{ej} \sum_i X_{ij} + \sum_j MIL_w * MIL_{ej} \sum_i X_{ij} +$$

$$\sum_j COM_w * COM_{ej} \sum_i X_{ij} + \sum_j PROX_w * PROX_{ej} \sum_i X_{ij} + \sum_j TRANS_w * TRA$$

$$\sum_j DEM_w * DEM_{eij} \sum_i X_{ij} \qquad (1)$$

The objective of this model (Equation 1) is to minimize the total weighted efficiency scores in order to select the optimum forward-staging location for all parts. The components used to determine the total weighted efficiency scores include the average CASREP time for parts to arrive in each location, access to MSC assets, availability of MILAIR, accessibility and frequency of COMAIR transportation, proximity to the OPAREA, ease of transferring material between locations, and historical demand of parts from each location.

Equation 1 is subject to:

$$\sum_j X_{ij} = 1 \qquad (2)$$

$$\sum_i X_{ij} \leq 1 \qquad (3)$$

$$1 \leq CAS_w, MSC_w, MIL_w, COM_w, PROX_w, TRANS_w, DEM_w \leq 5 \qquad (4)$$

$$0 \leq CAS_{ej}, MSC_{ej}, MIL_{ej}, COM_{ej}, PROX_{ej}, TRANS_{ej}, DEM_{eij} \leq 10 \quad (5)$$

Equation 2 ensures that the model places only one of each NIIN in a location to satisfy current inventory levels. Equation 3 prevents more than one of the same NIIN being placed at the same location. This constraint is placed in the event that inventory levels rise above current figures. Equations 4 and 5 limit the weighting and scoring scheme.

F. ASSUMPTIONS

The following are the key assumptions in optimizing BMD readiness in Sixth Fleet in no particular order of importance. First, the model assumes four BMD ships operating in the AOR and at least one BMD ship in the OPAREA conducting a BMD mission. Additionally, none of these ships have organic helicopters onboard. We assume MSC, COMAIR, and MILAIR operations and assets remain at their current posture levels. Furthermore, we assume no customs delays and all ports and airports will remain open during increased BMD posture levels.

The Forward 8 parts are utilized independent of each other, meaning they are equally critical to the system. For example, the Power Supply (NIIN 12583679) does not require the Power Inverter (NIIN 14657498) to restore the system as parts are independently critical of each other. Additionally, all Forward 8 parts must be stationed together.

We assume all parts are available within the supply system with no backordered requisitions. Finally, we assume transportation costs are negligible in the model because of the importance of the BMD mission and criticality of CAT 2, 3, or 4 CASREP materials.

V. RESULTS, RECOMMENDATIONS, AND CONCLUSIONS

Chapter V discusses the results and limitations of our model, recommendations to improve AEGIS BMD logistics in Sixth Fleet, and our overall conclusions. Additionally, we discuss our sensitivity analysis for variations on lead time and transferability.

A. LOCATION OPTIMIZATION RESULTS

1. Results for One of Each NIIN

The current inventory levels of Forward 8 parts in Sixth Fleet are one of each NIIN. Running the model under this assumption, Souda Bay is the optimal location to forward stage all of the Forward 8 parts. Table 3 shows the results of the model and the corresponding minimization scores, in which the lowest score is the optimal solution.

Table 3. Minimization Score Results for Allocating One of Each NIIN

Location	Minimization Score
Souda Bay, Greece	12.64
Sigonella, Italy	18.57
Rota, Spain	21.43
Haifa, Israel	21.74
Limassol, Cyprus	25.93

Souda Bay has the lowest CASREP lead time and has access to both military installations and COMAIR capabilities. With access to major transportation routes and proximity to the OPAREA, Souda Bay is the optimal solution for placement of the Forward 8 parts in the region.

2. Results for Two Parts of Each NIIN

Due to the high cost and low production of the Forward 8 parts, the most likely scenario is that only one part of each NIIN is forward staged. However, under the assumption that two parts of each NIIN are available, the model indicates that parts should be forward staged in Souda Bay and Sigonella, as illustrated in Table 3. With greater access to MILAIR and other logistics capabilities, Sigonella is centrally located and is the second optimal choice to forward stage parts.

3. Results for Three Parts

In the event three of each Forward 8 part become available, Table 3 indicates that Forward 8 parts should be positioned at Souda Bay, Sigonella, and Rota. Geographically, this option makes the most sense due to the coverage of the eastern, central, and western Mediterranean Sea. Beginning in 2014, Rota will be the homeport of BMD ships operating in Sixth Fleet and would be the next likely forward-staging location if three parts are available.

While the model indicates Rota would be the third optimal location to position a third set of parts, Rota has a slightly better score than Israel. Israel offers an ideal location due to its proximity to the OPAREA, low average CASREP lead time, and access to COMAIR.

4. Results for Four Parts

If the Navy allocated four of every part from the Forward 8 list, a set of all the Forward 8 parts would be assigned to each ship rather than positioning the parts ashore. Stationing the parts on each ship would eliminate the last tactical mile as ships would have instant access to these critical repair parts. Additionally, parts could be transferred between ships via RHIB or CLF as necessary. However, the low-production rates and high cost to stage one of every Forward 8 part on the four DDGs make this the most expensive and least attainable option.

B. SENSITIVITY ANALYSIS

Each logistics category is given a specific weight based on the importance level given by the model user. Table 4 shows the results of a sensitivity analysis that modifies the weight of each logistics category from low to high in order to examine the impact on the optimal location. By changing the weighting scheme, while keeping efficiency scores constant, we determined which logistics categories, if any, have the greatest impact on the optimal solution. The data within Table 4 indicate the rank order of each location.

Table 4. Results of Sensitivity Analysis for Weights of Logistics Categories

Sensitivity Analysis	CASREP Lead Time		MSC		MILAIR		COMAIR		Proximity		Transfer-ability		Demand	
Low/High Weight	**1**	**5**	**1**	**5**	**1**	**5**	**1**	**5**	**1**	**5**	**1**	**5**	**1**	**5**
Rota	3	3	4	3	4	3	4	3	3	4	4	3	3	3
Sigonella	2	2	2	2	2	2	2	2	2	2	3	2	2	2
Israel	4	4	3	4	3	4	3	4	4	3	2	4	4	4
Souda Bay	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cyprus	5	5	5	5	5	5	5	5	5	5	5	5	5	5

In Table 4, we examined the sensitivity of each logistics factor by assigning it the lowest and highest weight (1 and 5) and listing the resulting rank. For example, by assigning a low weight (1) to the first category, CASREP lead time, Souda Bay is ranked first and Cyprus is ranked last. By assigning a high weight (5) to CASREP lead time, Souda Bay is still ranked first and Cyprus is ranked last. This statement can be applied to each category in Table 4.

Even with changes to the weighting scheme, Souda Bay remains the optimal location to stage the Forward 8 parts. Regardless of weight designation, Souda Bay emerges with the minimum score while keeping all efficiency scores constant. Sigonella remains as the second optimal location across the majority of logistics factors, with the exception of transferability. As transferability decreases in importance, Israel becomes the second optimal location while Sigonella becomes the tertiary option. Due to the change in optimization order, transferability is the logistics category that carries the most influence when efficiency scores are kept constant. CASREP lead time and demand for each NIIN have no direct impact on optimization outcomes based on changing weighting schemes.

1. Variations on CASREP Lead Time

In the following subsections, we analyze variations of two key logistics factors, CASREP lead time and transferability, for each location. The results are displayed in Tables 5 and 6. We examined the variation of each efficiency score at each location by assigning it the lowest and highest scores (0 and 10) and keeping the weighting scheme constant. For example, by assigning a low efficiency score (0) to the first category, CASREP lead time at Rota, Souda Bay is ranked first and Rota is ranked second. By assigning a high efficiency score (10) to CASREP lead time at Rota, Souda Bay is still ranked first, but Rota is ranked fourth. This statement can be applied to each category to interpret Tables 5 and 6. Since our focus is to minimize the objective function, a low efficiency score is desirable and a high efficiency score is undesirable.

Keeping the weighting scheme constant, the following analysis focuses on how changes to efficiency scores of each location impact the optimization results. One of the most significant logistics categories affecting the optimization model is CASREP lead times. Table 5 indicates how decreasing or increasing CASREP lead times for each location, but keeping all other factors constant, affects overall optimization order.

Table 5. Results of Sensitivity Analysis for CASREP Lead Times

Sensitivity Analysis	CASREP Lead Time–Rota		CASREP Lead Time–Sigonella		CASREP Lead Time–Israel		CASREP Lead Time–Souda Bay		CASREP Lead Time–Cyprus	
Low/High Score	**0**	**10**	**0**	**10**	**0**	**10**	**0**	**10**	**0**	**10**
Rota	2	4	4	3	4	3	4	3	3	4
Sigonella	3	2	1	2	2	2	2	1	2	2
Israel	4	3	3	4	3	4	3	4	4	3
Souda Bay	1	1	2	1	1	1	1	2	1	1
Cyprus	5	5	5	5	5	5	5	5	5	5

The results in Table 5 indicate that improvement of average CASREP lead time to six days or less at Sigonella would make it the optimal location for the Forward 8 parts. With a CASREP lead-time average of more than 10 days, Sigonella has one of the longest lead times in the region and improvements to its lead times alone would make it the top site.

If average CASREP lead times at Souda Bay deteriorated to 10 days or more, Sigonella would again be the optimal location. If CASREP lead times in Rota decreased from the current average of eight days to six days or less, Rota would be the second forward-staging location for Forward 8 parts.

2. Variations on Transferability

Transferability underscores three legs of the mobility triad: commercial airlift, military airlift, and military sealift. Sensitivity analysis evaluates how the optimization model changes to varying transferability efficiency scores from each location. Once a location establishes a logistics capacity, such as a military airfield, it is unlikely that its capability will diminish beyond use. Therefore, this sensitivity analysis focuses only on improvements to the transferability components for each location so only low scores will be analyzed.

Table 6. Results of Sensitivity Analysis for Transferability

Sensitivity Analysis	Transferability-Rota	Transferability-Sigonella	Transferability-Israel	Transferability-Souda Bay	Transferability-Cyprus
Low Score	**0**	**0**	**0**	**0**	**0**
Rota	3	3	4	3	4
Sigonella	2	2	3	2	2
Israel	4	4	2	4	5
Souda Bay	1	1	1	1	1
Cyprus	5	5	5	5	3

Souda Bay remains the optimal location to stage Forward 8 parts independent of changing transferability efficiency scores. Improved access to COMAIR, MILAIR, and MSC assets would make Israel the second-best pre-positioning location in Sixth Fleet. Improving access to MILAIR includes the establishment of a fixed- and rotary- wing squadron along with access to a military airfield in Israel. Improvements to COMAIR would include increased volume of commercial delivery flights and additional commercial shipping carriers opening routes to Israel. MSC assets would have more logistical outbound replenishment trips from Israel.

As displayed in Table 6, improving the transferability factors of Cyprus, keeping all other factors constant, improves Cyprus to a tertiary staging location. Major MILAIR, COMAIR, and MSC asset logistics infrastructures or capabilities would have to be constructed or developed in order for Cyprus to achieve such an outcome.

C. MODEL LIMITATIONS

Producing a model that completely represents every aspect of Sixth Fleet and AEGIS BMD logistics is beyond the scope of this report. However, there are a few changes that would enhance this model and result in a more complete and valuable product.

First, Navy ships operate in a dynamic environment in which schedules often change to support emergent operations. Logistics operations are often ad hoc to support the changing schedules and demand for critical parts. Thus, while the data for the model are as accurate as possible, every CASREP and logistics scenario is unique based on the ship's mission and schedule. As in any model, more accurate information would lead to a more accurate model.

Second, Navy ships have been conducting the BMD mission in the Mediterranean Sea since 2011 as part of EPAA. Thus, only three years of data exist and more data would improve the accuracy of the model. More data will become available as AEGIS BMD ships are forward deployed in Rota and continue to operate in the Mediterranean Sea.

Additionally, the model does not include transportation cost considerations nor cost analysis for MSC assets, COMAIR, or MILAIR. Due to the AEGIS BMD program's designation as F/AD I and the importance of the BMD mission, we disregarded transportation costs. If these costs became a limiting factor, we could incorporate them into the model in the future.

Finally, the model does not exclusively focus on lead-time sensitivities or include cost considerations, as previously mentioned. A multi-objective programming approach could be used to weigh different objectives on selecting a forward-staging location based on importance: minimizing total lead times or minimizing total cost. Also, the weighted factor of each logistics category is subject to a user's discretion. This flexibility allows a user to add importance to certain parameters, but a future model could eliminate the weighted scheme in favor of inputs that are purely deterministic.

D. RECOMMENDATIONS

By increasing access to MILAIR and MSC, BMD ships would have increased access to logistics hubs. For example, a Helicopter Sea Combat Squadron (HSC) of MH-60Ss could be forward deployed to Souda Bay, Israel, or Cyprus during an increased BMD posture to decrease the last tactical mile and maximize the time a BMD ship remains on station. While Flight I and II DDGs do not have the capability to deploy with organic helicopters, they could maneuver to the MH-60S's maximum range, 420 NM, to receive the helicopter from a shore facility.

Another option to decrease the last tactical mile to deliver critical parts to BMD ships on station in the eastern Mediterranean Sea would be to leverage NATO Allies' assets. While this option is operationally and politically complex, Sixth Fleet could coordinate with NATO aircraft or CLF to deliver parts to BMD ships on station.

Finally, the demand for AEGIS parts will increase throughout the Fleet as the number of BMD ships is scheduled to increase and operational demand for BMD ships by COCOMs increases to meet emerging threats in Asia, Europe, and the Middle East. Therefore, the supply of repair parts must increase to meet the demand. Additionally, due to the time-critical nature of the BMD mission and its designation as an F/AD I program, the Navy should increase the supply and availability of AEGIS BMD parts throughout the Fleet in the supply system.

E. CONCLUSION

The model generated in this report optimizes the pre-positioning location of specific BMD parts based on factors and parameters used in the model. To meet this objective, the model had to incorporate factors that would reflect real-world logistics dynamics in Sixth Fleet. Consequently, this model examined a select

number of commercial shipping companies, logistics hubs, and military transport capabilities to provide critical parts in response to demand from BMD ships operating in the region. Historical data were used to assess the demand frequency of each part and the overall CASREP lead times for each location. The incorporation of weighted factors allows the model user to add importance to particular logistics elements.

Using sensitivity analysis to alter the weighting scheme, Souda Bay remains the optimal location to stage the Forward 8 parts followed by Sigonella. Furthermore, keeping the weighting scheme constant and varying the efficiency scores for CASREP lead time and transferability, we determined Sigonella would be the optimal location if the CASREP lead time improved, followed by Souda Bay. Furthermore, sensitivity analysis of all other logistics factors confirms Souda Bay as the optimal location.

Through our analysis and research, we determined NAVSUP GLS and NAVSUP WSS clearly identified the critical parts needed to be forward deployed in theater in the Forward 8. Additionally, Sixth Fleet and CTF 63 have reliable and proven procedures to deliver critical CAT 3 and 4 materials to BMD ships on station in the eastern Mediterranean Sea. However, based on our model and research, we have identified options to improve the stationing and delivery methods for the Forward 8 parts in Sixth Fleet.

The goal of this report was to find an optimal location to pre-position high-value, high-demand parts that are critical to BMD missions. This report shows that, after evaluating several logistics parameters, an optimal solution can be found. In the event the inventory level of these parts increases, the model outlines the secondary and tertiary solutions to optimize pre-positioning.

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